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INTERACTION OF SWITCH ACTUATION ON TRACKING WITH A FOUR-AXIS FLIGHT CONTROL (CROSS-COUPLING)

William B. DeBellis

December 1989
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This is the third in a series of investigations to generate a data base for multiaxis side arm flight controls. The purpose of this research is to determine the interaction between switch actuation and tracking performance while tracking in four axes. The research is required to specify the number and locations of switches that can be placed on the flight control. The long-range goal is to provide design recommendations and input to military specifications and standards. Tracking errors increase when switches associated with this control grip and controller mechanism are operated.

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INTERACTION OF SWITCH ACTUATION ON TRACKING WITH A FOUR-AXIS FLIGHT CONTROL (CROSS-COUPLING)

INTRODUCTION

This is the third in a series of investigations to generate a data base for multiaxis side arm flight controls. The purpose of this research is to determine the interaction between switch actuation and tracking performance while tracking in four axes. The research is required to specify the number and locations of switches that can be placed on the flight control. The long-range goal is to provide design recommendations and input to military specifications and standards.

BACKGROUND

In both a combined and separate effort, private industry and a Government agency (Ames Research Institute) have demonstrated that a single multiaxis side arm flight control can control helicopter flight. Practical and fundamental questions about the number of axes and about the authority and type of stabilization associated with the control are a basic part of these efforts.

To determine how this technology affects the current capabilities within the crew station, the Human Engineering Laboratory (HEL) has designed a series of investigations to fill this data void.

In the first investigation (DeBellis & Christ, 1986), the physical orientation and location of the controller and armrest within the crew station were determined based on the subjective comfort of the operator. Data were presented for both left- and right-handed personnel, male and female personnel, and pilots wearing and not wearing chemical and biological (CB) gloves.

In the second investigation (DeBellis, 1988), instrument flight rules (IFR) simulator flight performance was investigated based on the pilot wearing CB gloves and the orientation and location of the controller and armrest. It was shown that considerable latitude in controller location and flight with CB gloves did not result in a statistically significant degradation of simulator flight performance.

This investigation determined the tracking performance while operating the various mission-related switches on an OH-58 helicopter cyclic control head. The concern was that during switch operation, unintentional pressure applied to a closely coupled controller would affect tracking performance.

As an example, both the cyclic and collective controls currently have switches on top of each control's handgrip. These are used to interact with the various on-board helicopter subsystems, which must be operated while the pilot is actively controlling the helicopter. Normally, when a switch is

pressed by a finger or thumb, the hand tightens on the grip, but additional force inadvertently applied to the control does not disturb the flight of the helicopter. With the multiaxis control, however, the pressing of a switch and the balancing pressure may result in a control input because the pivot point is just below the handgrip. An unintentional control input of this nature is referred to as cross-coupling.

The cross-coupling will be affected by the type, axial direction, and location of switches as well as operator characteristics such as hand size, whether he or she is wearing gloves, and the force applied to the switch.

As a practical concern of having only one flight control in the cockpit, initial cockpit integration efforts may try to relocate switches from the removed collective control and place them on the single flight control head to operate helicopter subsystems. These switches may be less optimally located as the number of required switches increases.

OBJECTIVE

The objective of this investigation is to determine the effects of switch actuation on tracking performance.

METHOD

Participants

Twenty-six civilian and military volunteers from the Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, were used in this investigation. Personnel were male and right-handed. No other selection criteria were used.

Description

Standard fleet helicopters contain three isotonic controls: a cyclic control held by the right hand, a collective control held by the left hand, and anti-torque pedals. The cyclic control is either in front of the pilot and centered between the operator's legs or on the right side of the crew seat. It pivots at the floor for the center location and pivots above the floor for the side location. For both locations, it moves in the horizontal plane in both a fore-to-aft and a side-to-side direction. The collective control is on the left side of the crew seat. It pivots from a point below the floor and moves from a point beside the operator's knee to a point beside the upper torso. The anti-torque control are pedals that move inversely to one another with a linear motion in the horizontal plane.

The multiaxis flight control used in this investigation was an isometric control with a small amount of elastic movement and a pivot 4 inches below the center of the handgrip. The pivot responded to forces applied in the two

horizontal directions: the vertical direction and in rotation about the vertical axis. The horizontal motions were used for cyclic control, and the vertical motion was used for collective control. The twisting motion was used for yaw (anti-torque) control. Table 1 contains the characteristics of the controller.

Table 1

Controller Characteristics[a]

Parameter	Horizontal[b]	Axes Vertical	Rotational
Force over linear range (±)	20 lb	40 lb	60 in.-lb
Maximum allowed force (±)	160 lb	528 lb	1056 in.-lb
Sensitivity (±10%)	0.5 V/lb	0.3 V/lb	0.17 V/in.-lb
Defection at maximum force (±)	0.4 in.	0.1 in.	4°/in.-lb

[a]Model 404-G717, Measurement Systems, Inc.
[b]Lateral and longitudinal axes

An OH-58 helicopter cyclic control head was used as the handgrip. The controller with an armrest (see Figure 1) was mounted in the simulator to the right side of the operator. A tracking display was on top the glare shield 28 inches in front of the operator. A VAX® 11/780 computer and Adage graphics system generated the tracking symbology, collected the data, and controlled the sequencing of the experiment.

Figure 2 is an illustration of the tracking display. The tracking task was compensatory and required complex coordination in keeping multiple tracking symbols aligned. The horizontal bar moved both vertically and in rotation about its center. The small cross moved both vertically and from side to side. The fore-and-aft motion of the control was coupled to the vertical motion of the bar, and the side-to-side motion of the control was coupled to the rotation of the bar. The vertical motion of the control moved the cross vertically, and the twisting motion of the control moved the cross from side to side.

Figure 1. Multiaxis controller.

The directional motion of each symbol was driven by a forcing function consisting of four different sine waves with frequencies between one and five cycles per minute and amplitudes approximately ±10% of the display height. Each symbol axial motion was independent and not coupled together as it would when the operator was tracking symbology driven by a set of helicopter equations of motions. As a result, variability that correlated between axes is considered operator-induced cross-coupled tracking, and a correlation analysis was used to determine the strength of this effect.

Switches to be actuated were highlighted on the graphic representation of the handgrip shown at the bottom of the display (see Figure 2).

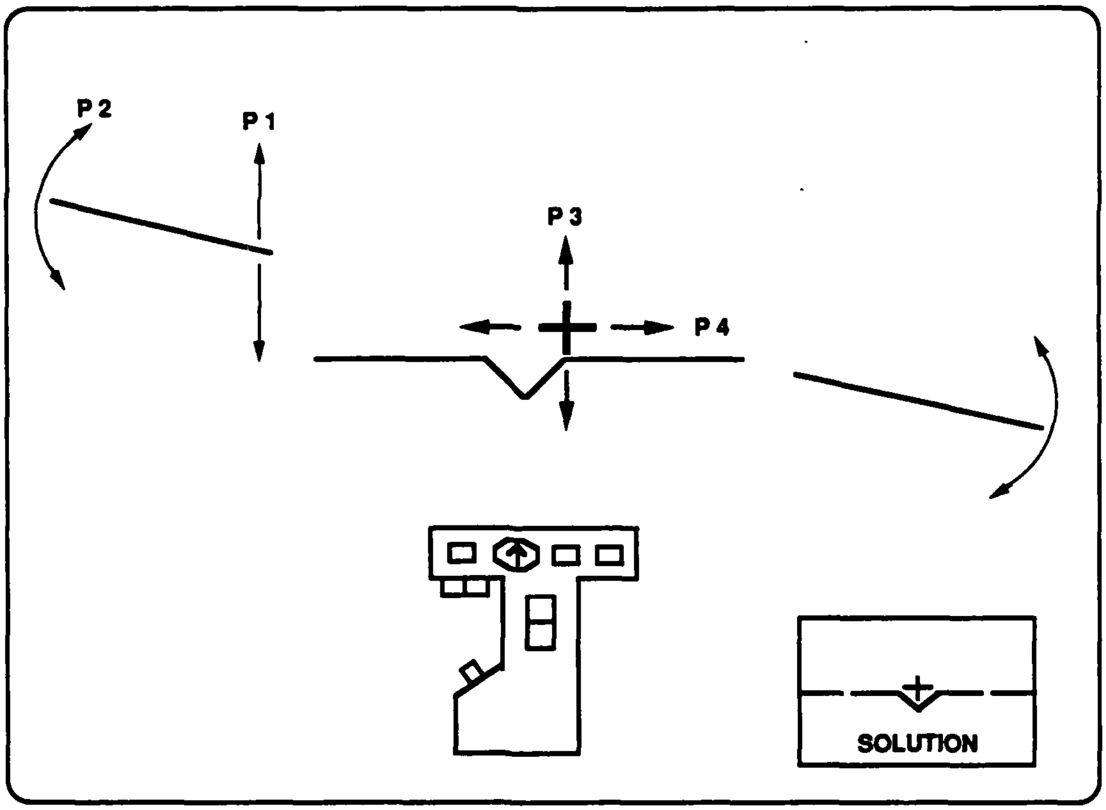

Figure 2. Display format.

The request for a switch actuation was presented randomly both in time interval and switch sequence with each switch being requested once per test run. When a wrong switch was pressed, the computer collected the data normally and adjusted the switch presentation sequence to include the initially requested switch later in the sequence. If a request for switch actuation was not acted upon in a reasonable time, the next switch was requested and the sequence adjusted.

If the second request for actuation was missed or if a switch was pressed for a second time, the data were ignored. When a switch was requested for the second time and not acted upon, it was handled as a missing data point. When a switch was released before the highlight was withdrawn, it was also handled as a missing data point.

A prompt, such as a tone or flashing message, to actuate a switch was not made because it was thought to be too disruptive. Even though a control was provided within the experiment to prompt the test participant when he froze on a switch, it was not used. Improper switch actuation did not halt the test run.

Figure 3 is an illustration of the switch designations on the OH-58 helicopter control head and the axial measurement variables. All switches are to be operated by the thumb of the right hand except for switches 10 and 11 which are to be operated by the index finger of the right hand. The "hat" switch (insert) is a four-way force displacement switch resembling a Chinese hat. It is 24 millimeters (mm) in diameter and cones upward 6 mm. Switches 2, 3, 4, and 5 were assigned to the four axes.

Switches 1, 6, and 12 are circular snap action switches. They are 9 mm in diameter and extend upward 8 mm; they displace downward 3 mm before actuation and provide a tactile feedback of actual activation. Switch 7 is similar except that at the actuation point the face of the switch is flush with the face of the control head. Switches 8 and 9 work in consonance with each other as a rocker switch with no tactile feedback. Switches 9 and 10 are the designation given to the guarded "trigger" switch. The first detent is switch 10 and the second detent is switch 11.

A line of data consisted of four channels of display variables, four channels of controller variables, subject and experimental conditions, and event marks for each switch activation. Data were recorded in half-second intervals. Each half-second interval contained data averaged over 20 points in a non-overlapping scheme.

A deviation measurement for the display variables was the offset distance in display resolution elements between a symbol and the neutral position. A deviation measurement for the controller variables was the difference in digitized transducer direct current voltage between the transducer voltage with the controller in the neutral or "at rest" position and the transducer voltage during tracking while force was being applied to the controller. These voltages were digitized with a resolution of 2047 units per 10 volts for a total of 4096 units from -10 to +10 volts.

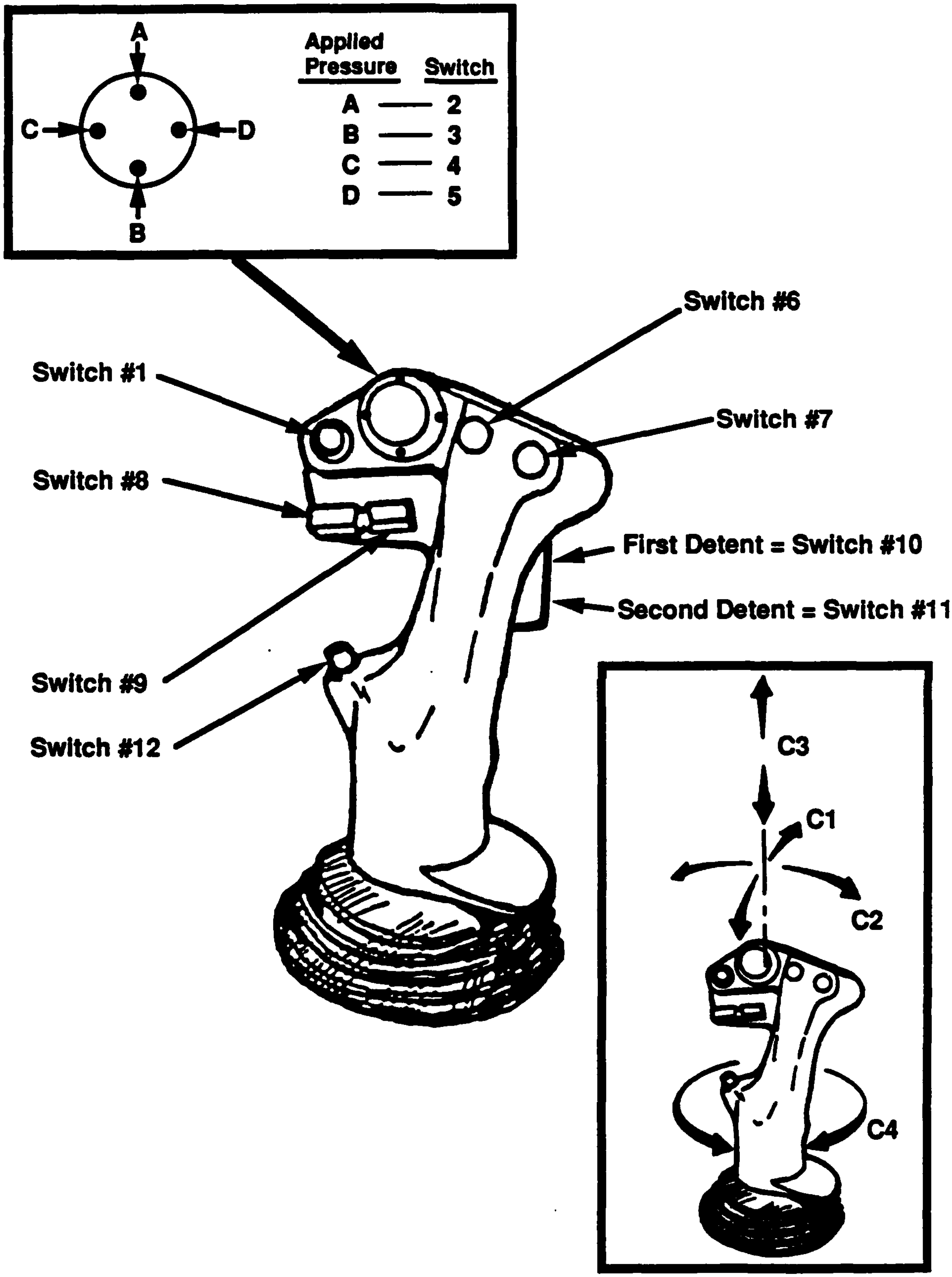

Figure 3. Switch location.

Procedures

The test participants, after signing a consent form, were briefed about the objective and procedures and were randomly assigned an order of presentation. They were then seated in the simulator and the seats were adjusted so that their seated upright position placed them at the cockpit design eye point, which was 28 inches from the tracking display. The location of the control and armrest were then adjusted for the comfort of the operator.

Training consisted of five 3-minute tracking runs with a 1-minute rest between the tracking runs. The training and experimental tasks were the same except for the control orientation. Four different orientations of the controller were used as experimental conditions. Training was accomplished with a control orientation set midway between the four experimental positions.

The four control orientations were (a) straight up, (b) 15° canted forward, (c) 15° canted forward and left, and (d) 15° canted left. Rotational orientation around the grip axis was adjusted for individual comfort.

The task of the operator was to align the bar horizontally with the center symbol and keep the cross in the center of the "v" and in line with the bar. When a switch was to be actuated, it was highlighted on the graphic representation of the control head just below the tracking symbology. The operator was to maintain the track and keep the switch depressed until the highlight was withdrawn.

Experimental Design

This investigation was conducted as a repeated measures design with 26 test participants. There were two predictor variables: control orientation and switch position. There were eight outcome variables, four of which were tracking performance (P1 through P4), and four were controller inputs (C1 through C4). These corresponded to the four motions within the tracking display and the four controller motions.

The up-to-down motion of the horizontal bar was variable P1. The rotational motion of the horizontal bar was variable P2. The up-to-down motion of the small cross was variable P3, and the side-to-side motion of the cross was variable P4. Force applied to the longitudinal axis of the controller was variable C1. Force applied to the lateral axis of the controller was variable C2. Force applied along the vertical axis was variable C3, and a rotational force applied about the vertical axis was variable C4.

The mean absolute deviation was selected as the appropriate variable for the test of the main effects and individual comparisons. The mean error was selected for the cross-coupling analysis because it contained directionality. A multivariate analysis of variance (MANOVA) procedure was used for the test of main effects. Individual comparisons were by Scheffé with subject by switch and subject by position used as error terms. The SAS statistical data package was used for all analyses.

RESULTS

Table 2 is the MANOVA. There was a statistically significant effect of operating switches but no significant effect of the four control positions. The analysis of variance of the display variable with the control variables used as regressors and the analysis of variance of the control variables with the display variables used as regressors did not change these results.

Tables 3 through 12 are the results of the statistical analysis on individual comparisons for switch effects. The bar connecting mean values indicates that means contained within the bar's length are not statistically significantly different. Using the mean absolute error, performance on all axes showed statistically significant better performance while no switch was being operated for most of the control and display variables.

A linear combination of the control performance variables (C1 through C4) was constructed and a Scheffé test of the pairwise combination analyzed (see Table 12). The analysis indicated that for the switches being operated, the least amount of variability occurred when switch 10 was being operated. Switches 3, 5, 9, and 10 were grouped with the condition of no switch being operated indicating that there was no statistically significant overall control variability between these conditions. Table 12 also indicates that overall control performance while operating all switches was statistically significantly worse than when no switch was being operated.

Switches 2, 4, and 6 were ranked low, which indicated that a high amount of force variability was being applied to the controller. Switches 2 and 4 are the "hat" switches being operated from the top and left sides, and switch 6 is centered on the vertical axis. There does not seem to be a trend for switches positioned at a greater distance from the vertical axis to have worse performances.

In a similar analysis, a linear combination of the tracking performance variables (P1 through P4) was investigated (see Table 7). Statistically, the condition of tracking while not operating switches was better than while operating switches. Switch 10 was again ranked the best, with switches 2, 8, and 12 ranked the worst.

Table 2

Multivariate Analysis of Variance

	SWITCH / SUBJECT(switch) (df=11/242)				POSITION / SUBJECT(position) (df=3/66)			
VARIABLES	ANOVA SS	MEAN SQUARE	F	PR > F	ANOVA SS	MEAN SQUARE	F	PR > F
PERFORMANCE								
P1	3553.51	323.046	5.45	0.0001	147.46	49.156	1.10	0.3538
(error)	14341.99	59.264			2938.28	44.519		
P2	80.91	7.355	5.95	0.0001	4.30	1.434	1.47	0.2317
(error)	299.19	1.236			64.54	0.977		
P3	1601.64	145.603	3.91	0.0001	490.79	163.597	1.33	0.2706
(error)	9010.55	37.233			8089.31	122.565		
P4	2330.96	211.906	3.73	0.0001	591.93	197.311	2.63	0.0570
(error)	13730.65	56.738			4942.62	74.888		
CONTROLLER								
C1	1342980.20	122089.109	8.27	0.000	17878.97	5959.658	0.36	0.7834
(error)	3572330.34	14761.695			1098212.99	16639.590		
C2	901430.47	81948.224	9.25	0.0001	14341.72	4780.573	0.46	0.7117
(error)	2144420.74	8861.242			687042.56	10409.735		
C3	131183.93	11925.812	7.26	0.0001	5448.89	1816.299	1.49	0.2243
(error)	397430.16	1642.273			80249.62	1215.903		
C4	1822611.12	165691.920	1.12	0.3433	339438.99	113146.332	0.76	0.5203
(error)	35688116.72	1642.273			9820139.73	148789.996		

Table 3

Variable P1

Scheffé's Test of Individual Means
MSE=59.2645 *MSD*=5.0903 *df*=242

Grouping	Mean	N	Switch
	10.466	92	sw2
	9.050	92	sw8
	9.021	92	sw12
	8.943	92	sw5
	8.830	92	sw1
	8.774	92	sw9
	8.498	92	sw4
	8.430	92	sw3
	8.378	92	sw7
	8.237	92	sw6
	8.188	92	sw10
	2.656	92	none

Table 4

Variable P2

Scheffé's Test of Individual Means
MSE=1.23634 *MSD*=0.7352 *df*=242

Grouping	Mean	N	Switch
	1.6632	92	sw4
	1.5423	92	sw12
	1.3499	92	sw2
	1.3107	92	sw9
	1.2471	92	sw6
	1.2213	92	sw3
	1.2089	92	sw8
	1.1283	92	sw7
	1.1154	92	sw10
	1.0624	92	sw1
	0.9462	92	sw5
	0.5559	92	none

Table 5

Variable P3

Scheffé's Test of Individual Means
MSE=37.2337 *MSD*=4.0347 *df*=242

Grouping	Mean	N	Switch
	9.6796	92	sw12
	8.1304	92	sw2
	7.8290	92	sw8
	7.3762	92	sw1
	7.0999	92	sw6
	6.9300	92	sw7
	6.9135	92	sw4
	6.8192	92	sw3
	6.1548	92	sw5
	5.9665	92	sw10
	5.8813	92	sw9
	4.7524	92	none

Table 6

Variable P4

Scheffé's Test of Individual Means
MSE=56.7338 *MSD*=4.9807 *df*=242

Grouping	Mean	N	Switch
	8.911	92	sw2
	8.758	92	sw8
	7.818	92	sw4
	7.317	92	sw7
	6.982	92	sw9
	6.658	92	sw5
	6.234	92	sw1
	6.221	92	sw12
	5.820	92	sw6
	5.656	92	sw10
	5.084	92	sw3
	3.580	92	none

Table 7

Variables (P1+P2+P3+P4)/4

Scheffé's Test of Individual Means
MSE=11.4819 *MSD*=2.2406 *df*=242

Grouping	Mean	N	Switch
|	7.2141	92	sw2
|	6.7113	92	sw8
|	6.6161	92	sw12
|	6.2232	92	sw4
|	5.9382	92	sw7
|	5.8755	92	sw1
|	5.7368	92	sw9
|	5.6757	92	sw5
|	5.6008	92	sw6
|	5.3884	92	sw3
|	5.2316	92	sw10
|	2.8860	92	none

Table 8

Variable C1

Scheffé's Test of Individual Means
MSE=14761.7 *MSD*=80.337 *df*=242

Grouping	Mean	N	Switch
|	198.20	92	sw6
|	187.73	92	sw12
|	183.33	92	sw4
|	176.37	92	sw7
|	173.53	92	sw8
|	173.45	92	sw2
|	172.72	92	sw5
|	162.84	92	sw3
|	161.84	92	sw1
|	160.39	92	sw9
|	154.52	92	sw10
|	54.55	92	none

Table 9

Variable C2

Scheffé's Test of Individual Means
MSE=8861.24 *MSD*=62.244 *df*=242

Grouping	Mean	N	Switch
	162.65	92	sw2
	151.95	92	sw4
	151.44	92	sw1
	148.70	92	sw8
	131.99	92	sw7
	130.87	92	sw6
	130.00	92	sw12
	127.17	92	sw9
	122.05	92	sw3
	108.83	92	sw5
	98.27	92	sw10
	52.08	92	none

Table 10

Variable C3

Scheffé's Test of Individual Means
MSE=1642.27 *MSD*=26.796 *df*=242

Grouping	Mean	N	Switch
	59.160	92	sw2
	58.155	92	sw12
	48.761	92	sw1
	48.237	92	sw9
	47.941	92	sw7
	46.066	92	sw4
	45.190	92	sw6
	43.881	92	sw8
	38.366	92	sw10
	37.410	92	sw5
	32.712	92	sw3
	16.915	92	none

Table 11

Variable C4

Scheffé's Test of Individual Means
MSE=147742 *MSD*=253.92 *df*=242

Grouping	Mean	N	Switch
	190.84	92	sw6
	70.59	92	sw4
	69.89	92	sw8
	68.29	92	sw2
	67.62	92	sw7
	61.60	92	sw9
	61.55	92	sw1
	48.60	92	sw12
	44.04	92	sw3
	43.01	92	sw5
	42.58	92	sw10
	18.21	92	none

Table 12

Variables (C1+C2+C3+C4)/4

Scheffé's Test of Individual Means
MSE=10938.6 *MSD*=69.156 *df*=242

Grouping	Mean	N	Switch
	141.27	92	sw6
	115.89	92	sw2
	112.98	92	sw4
	109.00	92	sw8
	106.12	92	sw12
	105.98	92	sw7
	105.53	92	sw1
	99.71	92	sw9
	90.49	92	sw5
	90.41	92	sw3
	83.43	92	sw10
	35.44	92	none

Tables 13 through 24 are the results of the cross-coupling analysis for tracking with and without individual switches being operated. The correlations between individual control channels and between individual display variables show the strength of the cross-coupling effect. For these tables, the top number is the Person Product-Moment Correlation Coefficients, and the bottom number is the probability that these coefficients are significant.

Table 13 is the correlation analysis during tracking without any switch being operated. This table shows the base value of cross-coupling which reflects the experimental setup including the orientation of the controller itself. As can be seen, there was no significant correlation among the controller variables C1 through C4; however, there was a significant correlation between the display variables of P3 and P4.

This relationship did not remain constant during switch operation; it changed, depending on which switch was in operation while tracking. What did remain constant across all conditions was the negative sign of the coefficient. When switches 1, 2, 3, 4, 5, and 10 were in operation, there was no longer a significant correlation, but when switches 6, 7, 8, 9, and 12 were in operation, a significant correlation remained.

These switches are on the right and left sides of the control head, and since the sign on the correlation did not change, switch location could not be isolated as having had a correlation with this effect. The values of the mean error and mean absolute error were checked and were spread within the distribution and not grouped high, which indicated that the test participants were responding similarly. An artifact in the display forcing functions was not the cause, since the switches were presented randomly and the no-switch operation condition was sampled throughout the test run between each switch operation condition.

When the "hat" switches (switches 3, 4, and 5) were operated from the bottom, left, and right sides with the thumb, switch 7 and switch 9, the control variables of C2 and C3, became significantly correlated with the same sign. When switch 2 was operated from the top, these variables were highly correlated but at the 0.056% level. The sign of the correlation remained the same under all conditions.

There were only six occurrences of a possible 48 when corresponding display and control variables were significantly correlated. This was unexpected as controller input was suspected of correlating highly with representative symbol motion in the display. As can be seen, the pitch variables were significantly correlated when switches 5, 6, 8, and 10 were operated, and the collective variables were significantly correlated when switches 5 and 8 were operated.

Table 13

Multiaxial Cross-Coupling Analysis During Tracking While not Operating Switches

(Correlation Coefficients / PROB > |R|)

	Performance variables				Controller variables			
	P1	P2	P3	P4	C1	C2	C3	C4
P1	1.0000 0.0000	0.1439 0.5124	-0.1200 0.5852	-0.0219 0.9210	0.3462 0.1056	-0.0800 0.7167	0.17171 0.4334	-0.0802 0.7158
P2	0.1439 0.5120	1.0000 0.0000	0.1729 0.4300	-0.2714 0.2102	-0.0968 0.6604	-0.2453 0.2591	-0.0870 0.6928	-0.1466 0.5043
P3	-0.1200 0.5850	0.1729 0.4300	1.0000 0.0000	-0.4974* 0.0157	-0.1441 0.5118	0.0460 0.8346	-0.2219 0.3087	-0.0517 0.8147
P4	-0.0219 0.9210	-0.2714 0.2100	-0.4974 0.0157	1.0000 0.0000	0.1195 0.5870	-0.2355 0.2793	-0.0548 0.8036	0.0917 0.6773
C1	0.3462 0.1056	-0.0968 0.6604	-0.1441 0.5118	0.1195 0.5870	1.0000 0.0000	-0.0896 0.6842	0.0731 0.7402	-0.2194 0.3144
C2	-0.0800 0.7167	-0.2453 0.2591	0.0460 0.8346	-0.2355 0.2793	-0.0896 0.6842	1.0000 0.0000	-0.1678 0.4439	-0.1721 0.4321
C3	0.1717 0.4334	-0.0870 0.6928	-0.2219 0.3087	-0.0548 0.8036	0.0731 0.7402	-0.1678 0.4439	1.0000 0.0000	0.1128 0.6082
C4	-0.0802 0.7158	-0.1466 0.5043	-0.0517 0.8147	0.0917 0.6773	-0.2194 0.3144	-0.1721 0.4321	0.1128 0.6082	1.0000 0.0000

*Significant at > 0.05

Table 14

Multiaxial Cross-Coupling Analysis During Tracking While Operating Switch #1

(Correlation Coefficients / PROB > |R|)

	Performance variables				Controller variables			
	P1	P2	P3	P4	C1	C2	C3	C4
P1	1.0000 0.0000	-0.1382 0.5293	-0.1500 0.4945	-0.0681 0.7573	0.1953 0.3718	0.1892 0.3872	0.1320 0.5481	-0.3612 0.0903
P2	-0.1382 0.5293	1.0000 0.0000	0.2849 0.1875	-0.2996 0.1647	-0.1266 0.5648	-0.1637 0.4553	0.2822 0.1920	0.2080 0.3409
P3	-0.1500 0.4945	0.2849 0.1875	1.0000 0.0000	-0.0398 0.8568	0.3285 0.1258	0.0483 0.8266	-0.3452 0.1066	-0.0943 0.6687
P4	-0.0681 0.7573	-0.2996 0.1647	-0.0398 0.8568	1.0000 0.0000	-0.0014 0.9947	-0.2826 0.1913	-0.2224 0.3076	0.1796 0.4120
C1	0.1953 0.3718	-0.1266 0.5648	0.3285 0.1258	-0.0014 0.9947	1.0000 0.0000	0.2886 0.1816	-0.1272 0.5629	0.0415 0.8509
C2	0.1892 0.3872	-0.1637 0.4553	0.0483 0.8266	-0.2826 0.1913	0.2886 0.1816	1.0000 0.0000	0.0740 0.7372	-0.5086* 0.0132
C3	0.1320 0.5481	0.2822 0.1920	-0.3452 0.1066	-0.2224 0.3076	-0.1272 0.5629	0.0740 0.7372	1.0000 0.0000	-0.0630 0.7749
C4	-0.3612 0.0903	0.2080 0.3409	-0.0943 0.6687	0.1796 0.4120	0.0415 0.8509	-0.5086 0.0132	-0.0630 0.7749	1.0000 0.0000

*Significant at > 0.05

Table 15

Multiaxial Cross-Coupling Analysis During Tracking While Operating Switch #2

(Correlation Coefficients / PROB > |R|)

	Performance variables				Controller variables			
	P1	P2	P3	P4	C1	C2	C3	C4
P1	1.0000 0.0000	0.1164 0.5967	0.3661 0.0857	-0.1331 0.5447	-0.4031 0.0564	-0.4293* 0.0409	-0.1368 0.5336	0.0777 0.7245
P2	0.1164 0.5967	1.0000 0.0000	0.2195 0.3142	-0.1353 0.5380	-0.0426 0.8468	0.3066 0.1548	0.2404 0.2691	-0.2560 0.2383
P3	0.3661 0.0857	0.2195 0.3142	1.0000 0.0000	-0.3330 0.1205	0.0664 0.7632	0.0873 0.6919	0.0203 0.9266	-0.3411 0.1112
P4	-0.1331 0.5447	-0.1353 0.5380	-0.3330 0.1205	1.0000 0.0000	0.0948 0.6669	-0.3288 0.1255	0.1492 0.4969	0.3649 0.0868
C1	-0.4031 0.0564	-0.0426 0.8468	0.0664 0.7632	0.0948 0.6669	1.0000 0.0000	0.0534 0.8087	-0.1726 0.4310	-0.0708 0.7480
C2	-0.4293 0.0409	0.3066 0.1548	0.0873 0.6919	-0.3288 0.1255	0.0534 0.8087	1.0000 0.0000	0.4041 0.0558	-0.2819 0.1925
C3	-0.1368 0.5336	0.2404 0.2691	0.0203 0.9266	0.1492 0.4969	-0.1726 0.4310	0.4041 0.0558	1.0000 0.0000	0.1136 0.6056
C4	0.0777 0.7245	-0.2560 0.2383	-0.3411 0.1112	0.3649 0.0868	-0.0708 0.7480	-0.2819 0.1925	0.1136 0.6056	1.0000 0.0000

*Significant at > 0.05

Table 16

Multiaxial Cross-Coupling Analysis During Tracking While Operating Switch #3

(Correlation Coefficients / PROB > |R|)

	Performance variables				Controller variables			
	P1	P2	P3	P4	C1	C2	C3	C4
P1	1.0000 0.0000	0.0817 0.7107	-0.0624 0.7772	-0.0644 0.7701	-0.2187 0.3159	-0.2548 0.2406	0.1829 0.4034	-0.1749 0.4248
P2	0.0817 0.7107	1.0000 0.0000	0.2201 0.3128	-0.1826 0.4042	-0.1706 0.4362	-0.1739 0.4275	0.0189 0.9315	-0.4569* 0.0284
P3	-0.0624 0.7772	0.2201 0.3128	1.0000 0.0000	-0.3807 0.0731	0.0961 0.6626	-0.0763 0.7293	0.0045 0.9835	0.1067 0.6277
P4	-0.0644 0.7701	-0.1826 0.4042	-0.3807 0.0731	1.0000 0.0000	-0.2087 0.3392	-0.3296 0.1245	-0.5577* 0.0057	0.3844 0.0701
C1	-0.2187 0.3159	-0.1706 0.4362	0.0961 0.6626	-0.2087 0.3392	1.0000 0.0000	0.0951 0.6658	0.5128* 0.0123	0.0067 0.9758
C2	-0.2548 0.2406	-0.1739 0.4275	-0.0763 0.7293	-0.3296 0.1245	0.0951 0.6658	1.0000 0.0000	0.4417* 0.0348	-0.2576 0.2352
C3	0.1829 0.4034	0.0189 0.9315	0.0045 0.9835	-0.5577 0.0057	0.5128 0.0123	0.4417 0.0348	1.0000 0.0000	-0.2269 0.2978
C4	-0.1749 0.4248	-0.4569 0.0284	0.1067 0.6277	0.3844 0.0701	0.0067 0.9758	-0.2576 0.2352	-0.2269 0.2978	1.0000 0.0000

*Significant at > 0.05

Table 17

Multiaxial Cross-Coupling Analysis During Tracking While Operating Switch #4

(Correlation Coefficients / PROB > |R|)

	Performance variables				Controller variables			
	P1	P2	P3	P4	C1	C2	C3	C4
P1	1.0000	0.06364	-0.0537	0.4644*	-0.0686	-0.2373	-0.2723	0.1863
	0.0000	0.7730	0.8076	0.0256	0.7557	0.2754	0.2086	0.3946
P2	0.0636	1.0000	0.0650	0.2690	-0.1033	-0.2326	-0.1084	0.0579
	0.7730	0.0000	0.7682	0.2145	0.6388	0.2855	0.6222	0.7927
P3	-0.0537	0.0650	1.0000	-0.2046	-0.3273	-0.0618	-0.3103	0.1045
	0.8076	0.7682	0.0000	0.3489	0.1273	0.7793	0.1495	0.6350
P4	0.4644	0.2690	-0.2046	1.0000	0.1924	-0.0578	-0.2825	0.2551
	0.0256	0.2145	0.3489	0.0000	0.3790	0.7933	0.1915	0.2399
C1	-0.0686	-0.1033	-0.3273	0.1924	1.0000	0.0066	-0.0616	-0.1519
	0.7557	0.6388	0.1273	0.3790	0.0000	0.9760	0.7799	0.4889
C2	-0.2373	-0.2326	-0.0618	-0.0578	0.0066	1.0000	0.6684*	0.1908
	0.2754	0.2855	0.7793	0.7933	0.9760	0.0000	0.0005	0.3830
C3	-0.2723	-0.1084	-0.3103	-0.2825	-0.0616	0.6684	1.0000	0.1030
	0.2086	0.6222	0.1495	0.1915	0.7799	0.0005	0.0000	0.6399
C4	0.1863	0.0579	0.1045	0.2551	-0.1519	0.1908	0.1030	1.0000
	0.3946	0.7927	0.6350	0.2399	0.4889	0.3830	0.6399	0.0000

*Significant at > 0.05

Table 18

Multiaxial Cross-Coupling Analysis During Tracking While Operating Switch #5

(Correlation Coefficients / PROB > |R|)

	Performance variables				Controller variables			
	P1	P2	P3	P4	C1	C2	C3	C4
P1	1.0000	0.1405	0.4394*	-0.7244*	-0.5200*	0.0701	-0.1924	-0.1541
	0.0000	0.5224	0.0359	0.0001	0.0110	0.7504	0.3790	0.4825
P2	0.1405	1.0000	0.0728	0.1441	-0.2730	-0.2432	0.0325	-0.0579
	0.5224	0.0000	0.7410	0.5118	0.2074	0.2633	0.8830	0.7928
P3	0.4394	0.0728	1.0000	-0.2087	-0.1957	0.1046	-0.2842	0.1678
	0.0359	0.7410	0.0000	0.3392	0.3706	0.6345	0.1886	0.4441
P4	-0.7244	0.1441	-0.2087	1.0000	0.0008	-0.1363	0.2186	0.4727*
	0.0001	0.5118	0.3392	0.0000	0.9968	0.5351	0.3162	0.0227
C1	-0.5200	-0.2730	-0.1957	0.0008	1.0000	0.3074	0.2900	0.0473
	0.0110	0.2074	0.3706	0.9968	0.0000	0.1536	0.1794	0.8303
C2	0.0701	-0.2432	0.1046	-0.1363	0.3074	1.0000	0.5076*	0.0517
	0.7504	0.2633	0.6345	0.5351	0.1536	0.0000	0.0134	0.8145
C3	-0.1924	0.0325	-0.2842	0.2186	0.2900	0.5076	1.0000	0.1821
	0.3790	0.8830	0.1886	0.3162	0.1794	0.0134	0.0000	0.4055
C4	-0.1541	-0.0579	0.1678	0.4727	0.0473	0.0517	0.1821	1.0000
	0.4825	0.7928	0.4441	0.0227	0.8303	0.8145	0.4055	0.0000

*Significant at > 0.05

Table 19

Multiaxial Cross-Coupling Analysis During Tracking While Operating Switch #6

(Correlation Coefficients / PROB > |R|)

	Performance variables				Controller variables			
	P1	P2	P3	P4	C1	C2	C3	C4
P1	1.0000 0.0000	0.0409 0.8528	0.1310 0.5512	-0.3285 0.1258	-0.6394* 0.0010	0.0358 0.8711	0.1039 0.6371	0.1917 0.3809
P2	0.0409 0.8528	1.0000 0.0000	-0.0455 0.8365	-0.0757 0.7312	-0.3890 0.0665	0.3443 0.1076	0.3213 0.1349	0.0467 0.8322
P3	0.1310 0.5512	-0.0455 0.8365	1.0000 0.0000	-0.6365* 0.0011	0.0893 0.6852	0.1235 0.5745	-0.1743 0.4262	-0.0915 0.6779
P4	-0.3285 0.1258	-0.0757 0.7312	-0.6365 0.0011	1.0000 0.0000	0.0530 0.8101	-0.3350 0.1182	-0.1207 0.5832	-0.0300 0.8919
C1	-0.6394 0.0010	-0.3890 0.0665	0.0893 0.6852	0.0530 0.8101	1.0000 0.0000	-0.0888 0.6869	-0.3551 0.0964	-0.3766 0.0765
C2	0.0358 0.8711	0.3443 0.1076	0.1235 0.5745	-0.3350 0.1182	-0.0888 0.6869	1.0000 0.0000	0.0819 0.7101	0.0210 0.9242
C3	0.1039 0.6371	0.3213 0.1349	-0.1743 0.4262	-0.1207 0.5832	-0.3551 0.0964	0.0819 0.7101	1.0000 0.0000	-0.1415 0.5196
C4	0.1917 0.3809	0.0467 0.8322	-0.0915 0.6779	-0.0300 0.8919	-0.3766 0.0765	0.0210 0.9242	-0.1415 0.5196	1.0000 0.0000

*Significant at > 0.05

Table 20

Multiaxial Cross-Coupling Analysis During Tracking While Operating Switch #7

(Correlation Coefficients / PROB > |R|)

	Performance variables				Controller variables			
	P1	P2	P3	P4	C1	C2	C3	C4
P1	1.0000	0.3563	0.1945	0.0667	-0.0249	-0.0505	-0.1339	-0.1294
	0.0000	0.0951	0.3736	0.7623	0.9099	0.8187	0.5424	0.5561
P2	0.3563	1.00000	0.0298	0.1037	-0.1985	0.3528	0.0989	-0.3529
	0.0951	0.0000	0.8924	0.6375	0.3638	0.0986	0.6533	0.0985
P3	0.1945	0.0298	1.0000	-0.6589*	-0.2878	0.1845	0.1585	0.0923
	0.3736	0.8924	0.0000	0.0006	0.1828	0.3993	0.4701	0.6753
P4	0.0667	0.1037	-0.6589	1.0000	0.0989	-0.1850	-0.3751	-0.1189
	0.7623	0.6375	0.0006	0.0000	0.6532	0.3979	0.0777	0.5888
C1	-0.0249	-0.1985	-0.2878	0.0989	1.0000	-0.1524	-0.0060	0.1532
	0.9099	0.3638	0.1828	0.6532	0.0000	0.4874	0.9783	0.4850
C2	-0.0505	0.3528	0.1845	-0.1850	-0.1524	1.0000	0.4918*	-0.2847
	0.8187	0.0986	0.3993	0.3979	0.4874	0.0000	0.0171	0.1879
C3	-0.1339	0.0989	0.1585	-0.3751	-0.0060	0.4918	1.0000	-0.2063
	0.5424	0.6533	0.4701	0.0777	0.9783	0.0171	0.0000	0.3449
C4	-0.1294	-0.3529	0.0923	-0.1189	0.1532	-0.2847	-0.2063	1.0000
	0.5561	0.0985	0.6753	0.5888	0.4850	0.1879	0.3449	0.0000

*Significant at > 0.05

Table 21

Multiaxial Cross-Coupling Analysis During Tracking While Operating Switch #8

(Correlation Coefficients / PROB > |R|)

	Performance variables				Controller variables			
	P1	P2	P3	P4	C1	C2	C3	C4
P1	1.0000	0.0027	-0.0564	0.1634	-0.4946*	0.2473	-0.3333	-0.1417
	0.0000	0.9900	0.7980	0.4561	0.0164	0.2552	0.1200	0.5188
P2	0.0027	1.0000	0.1545	0.2517	-0.0609	-0.0288	0.2234	0.2426
	0.9900	0.0000	0.4813	0.2466	0.7823	0.8962	0.3055	0.2646
P3	-0.0564	0.1545	1.0000	-0.5830*	-0.1007	-0.1136	-0.0117	-0.3456
	0.7980	0.4813	0.0000	0.0035	0.6474	0.6058	0.9574	0.1062
P4	0.1634	0.2517	-0.5830	1.0000	-0.0478	0.0161	-0.0964	0.7310*
	0.4561	0.2466	0.0035	0.0000	0.8284	0.9418	0.6616	0.0001
C1	-0.4946	-0.0609	-0.1007	-0.0478	1.0000	-0.0044	0.1219	0.0555
	0.0164	0.7823	0.6474	0.8284	0.0000	0.9838	0.5795	0.8014
C2	0.2473	-0.0288	-0.1136	0.0161	-0.0044	1.0000	0.2788	0.0842
	0.2552	0.8962	0.6058	0.9418	0.9838	0.0000	0.1977	0.7023
C3	-0.3333	0.2234	-0.0117	-0.0964	0.1219	0.2788	1.0000	0.3314
	0.1200	0.3055	0.9574	0.6616	0.5795	0.1977	0.0000	0.1223
C4	-0.1417	0.2426	-0.3456	0.7310	0.0555	0.0842	0.3314	1.0000
	0.5188	0.2646	0.1062	0.0001	0.8014	0.7023	0.1223	0.0000

*Significant at > 0.05

Table 22

Multiaxial Cross-Coupling Analysis During Tracking While Operating Switch #9

(Correlation Coefficients / PROB > |R|)

	Performance variables				Controller variables			
	P1	P2	P3	P4	C1	C2	C3	C4
P1	1.0000 0.0000	0.2994 0.1651	0.1585 0.4699	-0.1891 0.3874	-0.1549 0.4802	-0.1043 0.6356	-0.2911 0.1777	0.0042 0.9846
P2	0.2994 0.1651	1.0000 0.0000	0.2291 0.2929	-0.2915 0.1771	-0.0346 0.8752	0.2769 0.2007	0.1854 0.3969	0.1029 0.6400
P3	0.1585 0.4699	0.2291 0.2929	1.0000 0.0000	-0.4229 0.0443	0.0607 0.7832	-0.0726 0.7420	0.1966 0.3686	0.1426 0.5162
P4	-0.1891 0.3874	-0.2915 0.1771	-0.4229 0.0443	1.0000 0.0000	0.0167 0.9394	0.0290 0.8952	-0.1428 0.5157	0.3977 0.0601
C1	-0.1549 0.4802	-0.0346 0.8752	0.0607 0.7832	0.0167 0.9394	1.0000 0.0000	-0.1073 0.6259	0.0488 0.8250	-0.0313 0.8872
C2	-0.1043 0.6356	0.2769 0.2007	-0.0726 0.7420	0.0290 0.8952	-0.1073 0.6259	1.0000 0.0000	0.5636* 0.0051	0.0235 0.9152
C3	-0.2911 0.1777	0.1854 0.3969	0.1966 0.3686	-0.1428 0.5157	0.0488 0.8250	0.5636 0.0051	1.0000 0.0000	-0.0552 0.8023
C4	0.0042 0.9846	0.1029 0.6400	0.1426 0.5162	0.3977 0.0601	-0.0313 0.8872	0.0235 0.9152	-0.0552 0.8023	1.0000 0.0000

*Significant at > 0.05

Table 23

Multiaxial Cross-Coupling Analysis During Tracking While Operating Switch #10

(Correlation Coefficients / PROB > |R|)

	Performance variables				Controller variables			
	P1	P2	P3	P4	C1	C2	C3	C4
P1	1.0000	-0.0827	-0.0337	0.0699	-0.4301*	-0.0098	-0.0153	-0.0197
	0.0000	0.7075	0.8786	0.7512	0.0405	0.9644	0.9447	0.9286
P2	-0.08272	1.0000	-0.1100	-0.3443	-0.1260	0.4114	0.3654	-0.4782*
	0.7075	0.0000	0.6171	0.1076	0.5666	0.0511	0.0864	0.0210
P3	-0.0337	-0.1100	1.0000	-0.0893	-0.0137	-0.0626	0.1695	0.2023
	0.8786	0.6171	0.0000	0.6851	0.9503	0.7763	0.4394	0.3544
P4	0.0699	-0.3443	-0.0893	1.0000	0.1396	0.0759	-0.2538	0.0058
	0.7512	0.1076	0.6851	0.0000	0.5250	0.7304	0.2425	0.9788
C1	-0.4301	-0.1260	-0.0137	0.1396	1.0000	0.0223	-0.2927	0.1242
	0.0405	0.5666	0.9503	0.5250	0.0000	0.9194	0.1752	0.5722
C2	0.0098	0.4114	-0.0626	0.0759	0.0223	1.0000	0.0644	-0.3811
	0.9644	0.0511	0.7763	0.7304	0.9194	0.0000	0.7701	0.0727
C3	-0.0153	0.3654	0.1695	-0.2538	-0.2927	0.0644	1.0000	-0.2714
	0.9447	0.0864	0.4394	0.2425	0.1752	0.7701	0.0000	0.2102
C4	-0.0197	-0.4782	0.2023	0.0058	0.1242	-0.3811	-0.2714	1.0000
	0.9286	0.0210	0.3544	0.9788	0.5722	0.0727	0.2102	0.0000

*Significant at > 0.05

Table 24

Multiaxial Cross-Coupling Analysis During Tracking While Operating Switch #12

(Correlation Coefficients / PROB > |R|)

	Performance variables				Controller variables			
	P1	P2	P3	P4	C1	C2	C3	C4
P1	1.0000	-0.2466	0.1616	0.0898	0.1121	-0.0959	0.1777	0.3353
	0.0000	0.2566	0.4612	0.6834	0.6105	0.6631	0.4170	0.1178
P2	-0.2466	1.0000	0.2717	-0.3585	0.0788	-0.1111	0.3412	0.0383
	0.2566	0.0000	0.2098	0.0930	0.7207	0.6137	0.1110	0.8621
P3	0.1616	0.2717	1.0000	-0.6055*	0.0022	0.0743	0.1603	-0.0058
	0.4612	0.2098	0.0000	0.0022	0.9920	0.7360	0.4648	0.9789
P4	0.0898	-0.3585	-0.6055	1.0000	-0.0634	-0.0382	-0.3294	0.1312
	0.6834	0.0930	0.0022	0.0000	0.7738	0.8625	0.1248	0.5506
C1	0.1121	0.0788	0.0022	-0.0634	1.0000	-0.0779	0.0192	0.3172
	0.6105	0.7207	0.9920	0.7738	0.0000	0.7237	0.9307	0.1402
C2	-0.0959	-0.1111	0.0743	-0.0382	-0.0779	1.0000	0.0096	-0.1369
	0.6631	0.6137	0.7360	0.8625	0.7237	0.0000	0.9653	0.5331
C3	0.1777	0.3412	0.1603	-0.3294	0.0192	0.0096	1.0000	0.2682
	0.4170	0.1110	0.4648	0.1248	0.9307	0.9653	0.0000	0.2158
C4	0.3353	0.0383	-0.0058	0.1312	0.3172	-0.1369	0.2682	1.0000
	0.1178	0.8621	0.9789	0.5506	0.1402	0.5331	0.2158	0.0000

*Significant at > 0.05

The control variables of C1 and C3 were significantly correlated when operating switch 3, and the control variables of C2 and C4 were significantly correlated when switch 1 was operated.

DISCUSSION

As summarized in the Experimental Design section, there were two sources of outcome variables in this investigation: those associated with the display and those associated with the tracking control. Each of these sources had four channels of information, P1 through P4 and C1 through C4. Each of these

discrete measurements, along with experimental data, was recorded every half second. The discrete measurements were then transformed into mean deviation and the mean absolute deviation.

Each test participant, in turn, was measured four times, which corresponded to a data run on each of the four controller positions.

Before each data run, a sampling of the analog-to-digital channels was obtained and used as the current neutral reading of the signal. These neutral readings were used as the mean value for the deviation measurements. Continual initial sampling of the neutral position was necessary since the weight of the controller biased the signals differently depending on the position of the controller.

The data were prepared for analysis by first checking for any artifacts and incompleteness and then for sphericity and compound symmetry. When the comparison between the means and variances was made, it was noted that the variance initially increased as the test participant released switch pressure. A second-by-second analysis indicated that this transient response lasted 3 to 4 seconds. Although transient response is important in tracking research, for this investigation, it did not represent a condition of stable tracking while no switch was being operated, and a 4-second block of time immediately after the release of switch pressure was therefore bypassed in the analysis.

The trigger switch, which was operated by the index finger and positioned on the fore face of the controller, has two detent positions: switches 10 and 11. Switch 11 was the second detent position and required increased pressure to operate. Ten of the test participants were inconsistent in operating the second detent position. Since the MANOVA would balance the design by eliminating these test participants from the complete analysis based on the missing data points, a determination was made that switch 11 would be eliminated from the analysis. The rationale for this decision was that both switches 10 and 11 emanated from the same switch position and since no pressure measurement could be associated with these switches, switch 10 was representative of the switch position and the higher 'N' could be obtained.

One of the test participants was eliminated because he was wearing bifocal glasses and the horizontal stratification line in the lenses interfered with the horizontal line in the display and so indicated to the experimenter. Two more test participants were eliminated because their data indicated that only one switch was being operated even though all were being presented. It was not determined whether this was the result of computer error, test participant error, or instructional misunderstanding. As a result, 23 subjects were used in the analysis. The response characteristics of the test participants are contained in the Appendix.

The cross-coupling analysis was accomplished with the correlation procedure using mean error. The mean error was chosen as the more meaningful variable since it has directionality. Data were collapsed across control orientation.

CONCLUSIONS

Tracking errors increase when switches associated with this control grip and controller mechanism are operated.

Tracking performance resulted in high deviations when switches 2, 8, and 12 were operated, and controlling performance resulted in high deviations when switches 2, 4, and 6 were operated. These locations should not be used.

Switch 10 had consistently low tracking deviations. The tracking performance while operating this switch is probably the result of a uniform tightening of the controller's hand.

The tracking results on the remaining switch locations indicate that they should be used with caution. Performance when these switches are being operated depends on whether control or display variables are important and on the criticality of individual axes. Reference is made to the tables in the Results section.

The control orientation can be adjusted from straight up to 15° forward and to the left without statistically affecting tracking performance.

The longitudinal and rotational control channels need to be uncoupled based on the significant correlation while tracking without switches being operated.

The lateral and vertical control channels need to be uncoupled based on the five occurrences of significant correlation when switches are operated.

Contrary to a preconceived bias, the axial control variability was not consistent in correlating with corresponding associated variables on the display. In addition, the fact that a switch was farther off-axis did not result in more tracking errors.

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APPENDIX

TEST PARTICIPANT PERFORMANCE DATA

Table 1

Subjects' Parameter Performance
Variable P1 Scheffé Test
MSE=49.768 *MSD*=9.2449 *df*=33

Grouping	Mean	N	Subject
	18.398	48	6
	12.432	48	17
	10.839	48	2
	10.814	48	12
	10.394	48	18
	9.686	48	13
	9.680	48	5
	8.723	48	10
	8.657	48	8
	8.656	48	27
	8.640	48	23
	8.382	48	26
	7.510	48	11
	6.824	48	19
	6.777	48	24
	6.521	48	20
	6.289	48	4
	5.878	48	1
	5.877	48	22
	5.772	48	25
	5.001	48	7
	4.659	48	9
	4.241	48	3

Table 2

Subjects' Tracking Performance
Variable P2 Scheffé Test
MSE=1.00776 *MSD*=1.3155 *df*=33

Grouping	Mean	N	Subject
│	2.0490	48	27
│	1.9446	48	2
│	1.9386	48	13
│ │	1.6233	48	6
│ │	1.4642	48	12
│ │	1.3794	48	18
│ │	1.3658	48	22
│ │	1.2996	48	4
│ │	1.2216	48	26
│ │	1.2085	48	23
│ │	1.1834	48	10
│ │	1.1109	48	5
│ │	1.0828	48	19
│ │	1.0660	48	8
│ │	1.0387	48	7
│ │	1.0244	48	24
│ │	0.9975	48	20
│ │	0.9895	48	17
│ │	0.8671	48	25
│ │	0.7762	48	9
│ │	0.7403	48	11
│ │	0.5741	48	3
│ │	0.5615	48	1

Table 3

Subjects' Parameter Performance
Variable P3 Scheffé Test
MSE=18.2972 *MSD*=5.6056 *df*=33

Grouping	Mean	N	Subject
	20.2566	48	12
	20.0691	48	6
	13.0417	48	1
	9.2832	48	5
	9.0541	48	9
	8.6853	48	11
	6.6034	48	2
	6.4434	48	23
	6.3454	48	24
	6.3198	48	27
	5.5564	48	25
	5.3736	48	13
	5.1960	48	26
	5.1916	48	22
	4.6011	48	19
	4.3486	48	8
	4.3080	48	17
	3.9643	48	7
	3.7094	48	3
	3.6122	48	4
	2.9536	48	18
	2.7617	48	10
	2.4258	48	20

Table 4

Subjects' Parameter Performance
Variable P4 Scheffé Test
MSE=14.9426 *MSD*=5.0659 *df*=33

Grouping	Mean	N	Subject
	45.2948	48	6
	8.7884	48	5
	7.6247	48	25
	6.6424	48	27
	6.3340	48	7
	6.1784	48	1
	6.0896	48	24
	5.2992	48	13
	5.1798	48	22
	5.1151	48	9
	5.0426	48	12
	4.9890	48	17
	4.7848	48	11
	4.5459	48	19
	4.5255	48	2
	3.9600	48	4
	3.6556	48	26
	3.3061	48	18
	3.2988	48	3
	3.2041	48	8
	2.8138	48	23
	2.4886	48	20
	2.3255	48	10

Table 5

Subjects' Parameter Performance
Variables (P1+P2+P3+P4)/4 Scheffé Test
MSE=6.10078 *MSD*=3.2368 *df*=33

Grouping	Mean	N	Subject
	21.3462	48	6
	9.3943	48	12
	7.2157	48	5
	6.4149	48	1
	5.9782	48	2
	5.9169	48	27
	5.6796	48	17
	5.5744	48	13
	5.4302	48	11
	5.0590	48	24
	4.9550	48	25
	4.9010	48	9
	4.7765	48	23
	4.6137	48	26
	4.5083	48	18
	4.4036	48	22
	4.3189	48	8
	4.2635	48	19
	4.0845	48	7
	3.7902	48	4
	3.7483	48	10
	3.1083	48	20
	2.9558	48	3

Table 6

Subjects' Control Performance
Variable C1 Scheffé Test
MSE=13247.8 *MSD*=150.83 *df*=33

Grouping	Mean	N	Subject
	221.04	48	17
	204.40	48	26
	198.57	48	25
	196.06	48	22
	194.48	48	1
	191.50	48	23
	180.77	48	5
	177.63	48	9
	174.18	48	2
	174.15	48	8
	172.51	48	24
	170.55	48	20
	164.70	48	19
	161.46	48	11
	159.30	48	27
	153.42	48	13
	153.32	48	7
	152.77	48	4
	126.44	48	3
	124.99	48	12
	120.30	48	18
	119.99	48	10
	63.10	48	6

Table 7

Subjects' Control Performance
Variable C2 Scheffé Test
MSE=9939.21 *MSD*=130.65 *df*=33

Grouping	Mean	N	Subject
|	180.84	48	2
|	163.00	48	26
|	152.27	48	5
|	146.05	48	10
|	143.36	48	25
|	141.54	48	22
|	140.36	48	19
|	138.07	48	27
|	137.31	48	23
|	131.92	48	20
|	128.55	48	24
|	126.53	48	4
|	126.28	48	8
|	125.12	48	17
|	121.49	48	18
|	121.38	48	7
|	112.65	48	3
|	112.45	48	9
|	110.28	48	12
|	108.10	48	11
|	104.92	48	1
|	80.90	48	13
|	52.29	48	6

Table 8

Subjects' Control Performance
Variable C3 Scheffé Test
MSE=1538.08 *MSD*=51.395 *df*=33

Grouping	Mean	N	Subject
	91.545	48	5
	75.013	48	25
	66.666	48	2
	55.631	48	17
	50.577	48	9
	47.724	48	11
	45.778	48	24
	45.691	48	1
	45.424	48	23
	41.160	48	26
	39.512	48	22
	39.102	48	8
	39.022	48	10
	37.607	48	27
	35.234	48	20
	34.232	48	7
	32.811	48	18
	31.833	48	3
	31.015	48	12
	30.903	48	13
	29.804	48	6
	28.765	48	19
	26.974	48	4

Table 9

Subjects' Control Performance
Variable C4 Scheffé Test
MSE=147301 *MSD*=502.96 *df*=33

Grouping	Mean	N	Subject
|	314.16	48	13
|	97.41	48	25
|	76.06	48	24
|	71.84	48	6
|	70.43	48	5
|	66.02	48	9
|	59.92	48	27
|	58.61	48	2
|	55.57	48	11
|	55.55	48	26
|	54.31	48	17
|	53.49	48	7
|	53.01	48	12
|	52.08	48	23
|	51.28	48	1
|	48.85	48	3
|	48.63	48	22
|	43.12	48	18
|	42.57	48	8
|	38.05	48	4
|	34.17	48	10
|	31.65	48	20
|	31.28	48	19

Table 10

Subjects' Control Performance
Variables (C1+C2+C3+C4)/4 Scheffé Test
MSE=7679.18 *MSD*=114.84 *df*=33

Grouping	Mean	N	Subject
|	144.85	48	13
|	128.59	48	25
|	123.75	48	5
|	120.07	48	2
|	116.03	48	26
|	114.03	48	17
|	106.58	48	23
|	106.44	48	22
|	105.72	48	24
|	101.67	48	9
|	99.09	48	1
|	98.72	48	27
|	95.53	48	8
|	93.21	48	11
|	92.34	48	20
|	91.28	48	19
|	90.60	48	7
|	86.08	48	4
|	84.81	48	10
|	79.94	48	3
|	79.82	48	12
|	79.43	48	18
|	54.26	48	6